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<p>(54) Title: CODE-BASED OPTICAL NETWORKS, METHODS, AND APPARATUS</p> <p>(57) Abstract</p> <p>Optical communication systems (110) include a central station (103) that encodes data transmitted to multiplexing stations (111, 113) or user stations (117). The central station (103) also decodes data received from the multiplexing stations (111, 113) or user stations (117). Encoding and decoding are performed using codes, such as composite codes, that designate sources and destinations for data. The multiplexing stations (111, 113), user stations (117), and the central station (103) have address encoders and decoders that use, for example, fiber Bragg gratings to encode or decode optical signals according to a code such as a composite code derived by combining codes from one or more sets of codes. A passive optical network comprises one or more levels of multiplexing stations (111, 113) that use such address decoders and encoders to receive, decode, and encode data for transmission toward a central station (103) or a user station (117).</p>			

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**CODE-BASED OPTICAL NETWORKS, METHODS, AND APPARATUS****Field of the Invention**

5       The invention pertains to optical communication systems.

**Background of the Invention**

Optical fibers provide communication bandwidths as large as tens of Terahertz (THz). Such large bandwidths are too large to be fully used  
10 by single-channel communication systems that transmit data by amplitude modulation of a narrow-bandwidth optical carrier such as by directly modulating a distributed feedback laser. Factors limiting the bandwidth occupied by simple amplitude-modulated systems include bandwidth limits on available electronic and optical components such as  
15 optical modulators and detectors, as well as fiber dispersion.

In order to more fully use the available bandwidth of an optical fiber, multiplexing techniques have been developed that permit several communication channels to use the same optical fiber. The total fiber bandwidth used by these channels can be as large as the sum of the  
20 individual channel bandwidths. Conventional methods for multiplexing in optical communication systems include time-division multiplexing (TDM), wavelength-division multiplexing (WDM), and optical-code-division multiple access (OCDMA). These optical multiplexing methods are typically used in long haul, point-to-point communication and in  
25 short haul, ring-topology communication systems. Each of these methods has benefits as well as drawbacks associated with it.

A passive optical network (PON) capable of transmitting and receiving data from a large number of users simultaneously reduces cost and increases system reliability. A PON includes passive optical

components that route optically encoded data streams to and from designated users or network nodes. Communication systems based on the Synchronous Optical Network ("SONET") are not PONs since each user or node in a SONET system must have active equipment to detect

5 and demultiplex the data stream to recover data, and then retransmit data to the next user or node.

WDM systems are PONs, but each user of a WDM system is assigned a specific wavelength, so that WDM-based PONs are expensive and are not readily reconfigurable.

10 The use of OCDMA in a PON is advantageous in that data encoded onto a single transmitter can be distributed among many users because data is distinguished by a complex temporal code, and not wavelength as in WDM systems. Furthermore, CDMA coding has the advantage that the number of users is flexible, dependent on system  
15 usage. Also, most OCDMA implementations inherently offer hardware encryption by making channel decoding difficult without knowledge of the OCDMA encoding scheme. However, flexible tree-architecture PONs based on OCDMA typically require expensive equipment that must be located at each network node or an end-user location. Therefore,  
20 improved systems, methods, and architectures are needed for practical PON OCDMA systems.

#### Brief Description of the Drawings

FIG. 1 is a schematic block diagram of a communication system  
25 that includes a passive optical network (PON).

FIG. 2 is a schematic block diagram of the central station of FIG.  
1.

FIG. 3 is a schematic block diagram of a representative level-A multiplexing (mux) station.

FIG. 4 is a schematic diagram of a level-A address encoder.

FIG. 5 is a schematic diagram of a level-A address decoder.

FIG. 6 is a schematic diagram of a representative level-B mux station.

5 FIG. 7 is a schematic diagram of a level-B address decoder.

FIG. 8 is a schematic diagram of a level-B address encoder.

FIG. 9 is a schematic diagram of a representative user station of the communication system of FIG. 1.

10 FIG. 10 is a schematic diagram of a data-transmission system using 3-chip supercodes and 3-chip subcodes.

#### Detailed Description

FIG. 1 illustrates an optical communication system 100 comprising a central station 103 that distributes optically transmitted data (telephony, internet, video, etc.) to a number of geographically separated users 117<sub>11</sub>, . . . , 117<sub>nm</sub> that communicate with the central station 103 via a passive optical network 151. In addition, the central station 103 collects data from the user stations 117<sub>11</sub>, . . . , 117<sub>nm</sub> for remote transmission via an optical communication link 121. For convenience in describing the communication system 100 and other communication systems and apparatus, a "downstream direction" is defined as a data-propagation direction from a central station to a user. An "upstream direction" is a data-propagation direction from a user to a central station.

25 In the communication system 100, multiple data streams are multiplexed and demultiplexed by using optical-code-division multiple access (OCDMA). As shown in FIG. 1, the communication system 100 has a tree architecture with a level-A mux station 111 and level-B mux stations 113<sub>1</sub>, . . . , 113<sub>n</sub>. While FIG. 1 shows the level-A mux station

111 as a single branch from the central station 103, the central station 103 can communicate with multiple level-A mux stations.

FIG. 2 is a schematic diagram of the central station 103. The central station 103 comprises an input data module 201 that receives 5 data transmitted to or produced at the central station 103. As shown in FIG. 1, the central station 103 receives data from an external data link 121 or from the level-A mux station 111. Returning to FIG. 2, the input-data module 201 delivers an electrical data signal to an optical transmitter 203 that includes an optical emitter such as a distributed feedback laser. The laser is modulated in response to the electrical data signal so as to produce an optical data signal. Alternatively, an emitter can be provided that emits a continuous optical signal or a periodic series of optical pulses that are modulated with an electro-optic, acousto-optic, electro-absorptive, or other modulator. The modulation 10 can be amplitude-modulation or phase-modulation or a combination thereof. 15

A central station address encoder 205 receives the optical data signal from the optical transmitter 203 and encodes the modulated optical signal with an optical code such as a composite code serving as 20 an address for a selected user. In an alternative embodiment, the central station address encoder 205 can include encoders for every user (a total of  $n \times m$  encoders), or a smaller number of programmable encoders depending on system requirements, e.g., the aggregate downstream bandwidth and the number of users to be simultaneously addressed. 25

Composite codes are described in a U.S. Patent Application entitled CODES, METHODS, AND APPARATUS FOR OPTICAL ENCODING AND DECODING, co-filed with the present application and incorporated herein by reference. Representative encoders and decoders

using fiber Bragg gratings are described in U.S. Patent App. No. 09/354,851, TIME-WAVELENGTH MULTIPLE ACCESS COMMUNICATION SYSTEM that is incorporated herein by reference.

The composite codes are made of one or more code sets, each 5 code set corresponding to the number of mux levels. In the two-node (two mux levels) network of FIG. 1, the central station address encoder 205 applies composite codes having two levels A, B corresponding to level-A codes and level-B codes. If a third group of nodes were provided (i.e., if a level-C mux station were placed between the level-B mux 10 stations 113<sub>1</sub>, . . . , 113<sub>n</sub> and user stations 117<sub>11</sub>, . . . , 117<sub>nm</sub> to provide a third level of coding), then the central station address encoder 205 could apply the level-C codes. In such a case, the composite codes would include A-level, B-level, and C-level codes. Composite-code encoders can be configured in a variety of ways as described in the 15 references cited above.

Returning further to FIG. 2, an output module 207 of the central station 103 delivers combined optically coded (composite-coded) data signals from the encoders of the central station address encoder 205, and delivers a coded optical signal to the level-A mux station 111. The 20 coded signal delivered to the level-A mux station 111 is encoded with level-A and level-B codes that designate a user station to which data is to be delivered.

The central station 103 further comprises an input module 209 that receives optical signals from the level-A mux station 111 and 25 delivers optical signals to a central station address decoder 211 that decodes the level A and level B codes with which the optical signals are encoded. After the optical signals are thus decoded, an optical receiver 213 produces an uncoded electrical signal corresponding to the decoded

optical signal, and an optical transmitter ("output data module") 215 transmits a corresponding optical signal on the communication link 121.

FIG. 3 is a schematic diagram of the level-A mux station 111. An input module ("input means") 301 of the level-A mux station 111 accepts optical, composite-coded data signals from the central station 103. The input module 301 directs the optical data signals to a level-A address decoder/router 303. Output modules ("output means") 305<sub>1</sub>, . . . , 305<sub>n</sub> receive optical data signals from the level-A address decoder/router 303, split the received optical data signal into  $n$  optical data signals, and transmit these signals to respective level-B mux stations 113<sub>1</sub>, . . . , 113<sub>n</sub>.

The level-A mux station 111 also includes input modules ("input means") 307<sub>1</sub>, . . . , 307<sub>n</sub> that receive optical data signals from respective level-B mux stations 113<sub>1</sub>, . . . , 113<sub>n</sub>. A level-A address encoder 309 applies a level-A code to the received optical signals and directs the encoded optical signals to an output module ("output means") 311 for delivery to the central station 103.

FIG. 4 is a schematic diagram of the level-A address decoder/router 303. A beam splitter ("beam splitting means") 403 or a fiber directional coupler receives optical signals from the input module 303 and directs portions of the optical signals to optical circulators 405<sub>1</sub>, . . . , 405<sub>n</sub> that, in turn, direct respective portions of the optical signals to corresponding complex fiber Bragg gratings 401<sub>1</sub>, . . . , 401<sub>n</sub> that decode level-B codes. Decoded optical signals are delivered to corresponding outputs 409<sub>1</sub>, . . . , 409<sub>n</sub> that deliver a respective decoded optical signal to a corresponding level-B mux station. The optical signals for the respective level-B mux stations 113<sub>1</sub>, . . . , 113<sub>n</sub> can be broadcast, and data not intended for delivery to a particular level-B mux station (and ultimately to a selected user station) is not properly

decoded at the decoder/router 303. For data decoded with an unmatched decoder, the optical signal is typically a noise-like, low-power signal.

FIG. 5 is a schematic diagram of the level-A address encoder 309.

5 Level-B coded optical signals are received at corresponding inputs 509<sub>1</sub>, . . . , 509<sub>n</sub> and delivered to respective optical circulators 511<sub>1</sub>, . . . , 511<sub>n</sub> and respective fiber Bragg gratings 513<sub>1</sub>, . . . , 513<sub>n</sub>. After encoding with level-A codes by the fiber Bragg gratings 513<sub>1</sub>, . . . , 513<sub>n</sub>, encoded optical signals are combined by a beam combiner ("beam 10 combining means") 515 for delivery to the output module 311 and the central station 103.

15 FIG. 6 is a schematic diagram of a representative level-B mux station 113<sub>i</sub>. The level-B mux station 113<sub>i</sub> includes an input module ("input means") 601<sub>i</sub> that accepts an optically coded data signal from the level-A mux station 111. A level-B address decoder/router 603<sub>i</sub> receives the optical data signal and splits the optical data signal into  $m$  corresponding optical data signals 604<sub>i1</sub>, . . . , 604<sub>im</sub>, corresponding to the  $m$  user stations 117<sub>i1</sub>, . . . , 117<sub>im</sub>. Output modules 607<sub>i1</sub>, . . . , 607<sub>im</sub> transmit the split optical data signals 604<sub>i1</sub>, . . . , 604<sub>im</sub>.

20 FIG. 7 is a schematic diagram of the representative level-B address decoder/router 603<sub>i</sub>. A beam splitter ("beam splitting means") 703<sub>i</sub> or a fiber directional coupler receives an optical signal from the level-A mux station 111 and directs respective portions of the optical signal to optical circulators 705<sub>i1</sub>, . . . , 705<sub>im</sub> that, in turn, direct the 25 respective portions to corresponding fiber Bragg gratings 701<sub>i1</sub>, . . . , 701<sub>im</sub> that decode level-B codes. The optical signal from the level-A mux station 111 can be broadcast to the respective level-B mux station because data not intended for delivery to a particular level-B mux station (and ultimately to a selected user station) is not properly

decoded in the decoder/router 603<sub>i</sub>. For data decoded with an unmatched decoder, the optical signal is typically a noise-like, low-power signal and data is not readily recovered from such signals.

FIG. 8 is a schematic diagram of the level-B encoder 611<sub>i</sub>. Optical signals are received from user stations 117<sub>ii</sub>, . . . , 117<sub>im</sub> at respective inputs 801<sub>ii</sub>, . . . , 801<sub>im</sub> and delivered to respective optical circulators 803<sub>ii</sub>, . . . , 803<sub>im</sub> and fiber Bragg gratings 805<sub>ii</sub>, . . . , 805<sub>im</sub> that encode level-B codes. Encoded optical signals propagate along fiber lengths 807<sub>ii</sub>, . . . , 807<sub>im</sub> to a beam combiner ("beam combining means") 811<sub>i</sub>, and the combined optical signal is delivered to the level-A mux station 111.

The user stations 117<sub>ii</sub>, . . . , 117<sub>nm</sub> include respective interface modules, such as a representative interface module 901<sub>ij</sub> shown in FIG. 9. The interface module 901<sub>ij</sub> comprises an output module ("output means") 903<sub>ij</sub> and an input module ("input means") 905<sub>ij</sub> that send data to and receive data from a corresponding level-B mux station 113<sub>i</sub>. The input module 905<sub>ij</sub> receives a decoded optical signal from the corresponding decoder of the level-B mux station 113<sub>i</sub>. An optical receiver 907<sub>ij</sub> converts the decoded optical signal into a corresponding electrical signal. If the decoded optical signal originated at the central station 103 and was encoded with the level-A and level-B codes associated with the selected user station 117<sub>ij</sub>, then the electrical signal includes a series of data pulses. If the level-A and level-B codes applied at the central station 103 have not been properly decoded, then the electrical signal is a noise-like signal that can include some electrical pulses similar to data pulses but having smaller magnitudes. The optical receiver 907<sub>ij</sub> can include circuitry for removing or attenuating these smaller pulses and the noise-like background by thresholding and/or digitization, producing an enhanced electrical data output signal. The

data output module delivers the electrical data output signal to a module output 911<sub>ij</sub>.

For communication in an upstream direction, i.e., from a user station 117<sub>ij</sub> towards the central station 103, an input module 913<sub>ij</sub>

5 receives data from a user input 915<sub>ij</sub>. The received data modulates an optical transmitter ("modulated optical source") 917<sub>ij</sub> and the output module 903<sub>ij</sub> transmits an uncoded optical signal to a level-B mux. The optical transmitter 917<sub>ij</sub> can include a laser diode that is directly modulated by the received data, or that is modulated by an electro-

10 optic, acousto-optic, electro-absorptive, or other modulator.

Corresponding level-A and level-B mux stations apply level-A and level-B codes to the uncoded optical signal, and the coded signal arrives at the central station 103 where it can be decoded for transmission by stripping the level-A and level-B codes that indicate the data source.

15 Returning to FIG. 1, the PON 151 includes coders (encoders and decoders, not shown) that apply and strip codes from optical data signals. These coders require no power, nor is an optical-to-electrical conversion needed in the PON 151. In some cases, partially encoded and decoded optical signals are broadcast, but data generally cannot be

20 recovered from these broadcast optical signals unless decoded and encoded with matching codes. Hence, the PON 151 is "secure."

The embodiments described herein comprise encoders and decoders that include optical circulators and reflective complex fiber Bragg gratings. Other coding methods and apparatus can be used.

25 Such methods and apparatus also apply selected linear spectral transforms to optical signals. Furthermore, other methods and apparatus, such as beam splitters or fiber couplers, can be used to separate counterpropagating optical data signals instead of optical circulators. Representative optical encoders and decoders include

passive diffractive devices such as Bragg gratings and fiber Bragg gratings as described in, for example, U.S. Patent No. 5,812,318; U.S. Patent Application Nos. 09/115,331, SEGMENTED TASM GRATINGS, 09/120,959, SEGMENTED COMPLEX FIBER GRATING, and

5 09/354,851, TIME WAVELENGTH MULTIPLE ACCESS COMMUNICATION SYSTEM. These documents are incorporated herein by reference.

The communication system 100 of FIG. 1 can include optical amplifiers if necessary, based on system-design parameters such as

10 fiber loss, desired signal-to-noise level, intended number of users, acceptable bit-error rate, and others. Dispersion compensation can be provided in the PON 151 and a wavelength-division-multiplexed (WDM) layer can be provided in addition to the code layer. In addition, embodiments are discussed with reference to optical signals that are

15 electromagnetic fields of wavelength from about 300 nm to 0.1 mm. However, embodiments using longer or shorter wavelength electromagnetic fields are possible and electrical voltages carried by conductors such as wires can be used as well.

For convenience in describing embodiments, decoders were

20 referred to as "stripping" a code from a signal. Decoding generally permits data recovery by a detector, and decoding need not restore a signal exactly to its pre-encoded form. In addition, a signal from which a code has been stripped can be referred to as a "decoded" signal. Finally, for clarity, encoders and decoders are referred to in the above

25 description, but can be more generally referred to as "coders."

For convenience, composite codes that include two code levels and suitable for use in a passive optical network and in address encoders/decoders are described with reference to FIG. 10. FIG. 10 is a schematic of a data transmission system 1001 that produces a data

signal 1003 from a data source 1005. As shown in FIG. 10, the data signal 1003 is represented as a binary, on-off modulation of an electromagnetic carrier such as an optical carrier. The on-off modulation is selected for convenience only, and other modulations can include

5 phase, amplitude, intensity, and frequency modulation. In addition, non-binary modulation having more than two modulation levels can be used.

A supercode encoder 1007 receives the data signal 1003 and applies a predetermined code  $R_i$  selected from a code set R to the data signal 1003. For purposes of illustration, a code  $R_i = \{1, -1, 1\}$  is

10 selected and applied to a representative bit 1009 of the data signal 1003. As specified by the code R, the encoder 1007 receives the bit 1009 and transforms the bit into a "supercoded" bit packet 1011. The supercoded bit packet 1011 includes super-coded bits ("superbits") 1013-1015 that are relatively delayed by a delay time  $T_{RC}$ , wherein  $T_{RC}$  is a supercode chip duration. In addition, the phase of the superbit 15 1014 is inverted, while the phases of the superbits 1013, 1015 are unchanged. The encoder 1007 applies the code  $R_i$  to the entire data signal 1003 to produce a supercoded data signal that is a sum of superbits corresponding to all respective bits of the data signal 1003.

20 A subcode encoder 1017 receives the supercoded data signal and applies a code  $S_i$  selected from a code set S. For purposes of illustration, a code  $S_i = \{-1, 1, -1\}$  is selected. The code  $S_i$  is applied to the supercoded bit packet 1011 to produce a combined subcoded and supercoded ("composite-coded") bit packet 1021 that includes

25 subcoded bits 1023, 1025, 1027, corresponding to respective superbits 1013, 1014, 1015. The encoder 1017 encodes each of the supercoded bits 1013-1015 by relatively delaying portions by a delay time  $T_{SC}$  wh rein  $T_{SC}$  is a subcode chip duration, and changing the phase of the supercoded bits 1013, 1015, to produce the corresponding subcoded

bits 1023, 1025, 1027. The encoder 1017 applies the code  $S_i$  to the supercoded data signal, producing a composite-coded data signal.

The encoders 1007, 1017 apply codes from respective sets R, S to the data signal 1003. If the sets R, S contain  $N_R$  and  $N_S$  codes, 5 respectively, then  $N_R \times N_S$  different encodings are available. For example, if sets R, S each include 5 codes, then 25 encodings are possible. Thus, the number of available encodings increases as the product of  $N_R$  and  $N_S$  increases so that large numbers of encodings are possible even with small code sets. In addition, the sets R, S can be 10 subsets of a large code set and can include different or identical codes. In this way, a set of N codes can be used to produce  $N^2$  different encodings.

FIG. 10 illustrates encoding, with two sets of codes (sets R, S), but additional code sets can be used to further increase the number of 15 available encodings. Subcode bits 1013-1015 can be further encoded with a code set Q having  $N_Q$  codes, so that the number of available encodings is  $N_R \times N_S \times N_Q$ . Codes obtained by combining two or more code sets such as the code sets R, S are referred to herein as "composite codes." Composite codes using code sets R, S and code 20 sets R, S, Q are suitable for networks having two and three levels of address encoding/decoding, respectively.

The codes  $R_i$ ,  $S_i$  used above are selected as representative examples. More generally, codes include two or more "chips" that specify modulations to be applied to a signal. The chip modulations are 25 applied to a signal at relative times differing by a chip duration  $T_c$ . Thus, a code and a chip duration specify an encoding of a data signal. A supercode is further specified by an interchip duration. A code R, having a total duration  $T_R$ , a number of chips  $N_R$ , and a chip duration  $T_{RC}$ , and a code S, having a total duration  $T_S$ , a number of chips  $N_S$ , and chip

duration or interchip delay  $T_{sc}$ , are effectively orthogonal as decoded if  $T_R \leq T_{sc}$ . A composite code can be produced from the code R (a subcode), and from the code S (a supercode). The composite code has a given duration equal to the duration of the supercode and has a

5 number of chips equal to the product of the number of chips of the subcode and the supercode. The chip duration is equal to the subcode chip duration. In the composite code, the subcode is repeated a number of times equal to the number of chips in the supercode.

Code sets and chip durations of supercodes and subcodes (and

10 sub-subcodes) are preferably selected so that a data signal encoded with a particular composite code is decoded only with a matching decoding composite code. Decoding with an unmatched composite code produces only a noise-like background or low amplitude "sidelobes" or "crosstalk."

15 Given temporal orthogonality between a supercode and the subcode (i.e., low-amplitude cross-correlation and noise-like background), composite code sets of sufficient orthogonality can be generated from a code set with a small number of chips if the codes of the code set are sufficiently orthogonal. A code in a composite code set

20 is generated by using a selected code of the code set as a supercode and another selected code of the code set as a subcode. A composite code set comprises all combinations of supercodes and subcodes. For example, if a code set has  $M$  codes each containing  $N_m$  chips, then the composite code set contains  $M \times M$  codes each having  $N_m \times N_m$  chips.

25 Having illustrated and demonstrated the principles of the invention, it should be apparent to those skilled in the art that the embodiments described can be modified in arrangement and detail without departing from such principles. We claim as the invention all that comes within the scope of these claims.

What is claimed is:

1. A communication system, comprising:
  - a central station that receives an optical data signal and applies a composite code to the optical signal, the composite code including a first code and a second code, so as to produce a composite-coded optical signal;
  - a first-level mux station that receives the composite-coded optical signal and decodes the first code from at least a portion of the optical signal, producing a first-level decoded optical signal;
  - a second-level mux station that receives the first-level decoded optical signal and decodes the second code from at least a portion of the optical signal, thereby producing a fully decoded optical signal; and
  - a user station that receives the fully decoded optical signal.
- 15 2. The communication system of claim 1, wherein the first-level mux station includes a reconfigurable encoder for applying a selected composite code.
- 20 3. The communication system of claim 1, wherein the central station applies a composite code selected from a set of composite codes.
- 25 4. The communication system of claim 3, wherein composite codes are generated from a set of first-level codes and a set of second-level codes.
5. A central station for an optical network, comprising:

a receiver that receives a first optical data signal and produces a corresponding electrical data signal;

a transmitter that produces a second optical data signal based on data defined by the electrical data signal; and

5 an encoder that applies a code to the second optical data signal.

6. The central station of claim 5, wherein the code applied by the encoder is a composite code.

10 7. The central station of claim 5, wherein the code is an address code that designates an intended destination for at least some of the data defined by the electrical data signal.

8. A multiplexing station for an optical network, comprising:

15 an address decoder that receives a signal containing data and coded according to an address code and strips the code from the signal, wherein the address code designates a destination for at least a portion of the data; and

an address encoder that receives a signal containing data and

20 encodes the signal to identify a destination of at least some of the data.

9. The multiplexing station of claim 8, wherein the address decoder strips an optical code from the signal.

25 10. The multiplexing station of claim 9, wherein the code is a composite code.

11. The multiplexing station of claim 8, wherein the address encoder applies an optical code.

12. The multiplexing station of claim 11, wherein the code is a composite code.

5        13. The multiplexing apparatus of claim 8, wherein the address encoder includes at least one fiber Bragg grating that applies the code.

14. The multiplexing apparatus of claim 8, wherein the address decoder comprises at least one fiber Bragg grating that strips the code.

10

15. The multiplexing apparatus of claim 14, further comprising an optical circulator that directs the signal to at least one fiber Bragg grating.

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16. A method of broadcasting an optical signal to a plurality of user stations for data recovery only by a selected user, comprising:  
selecting a code for the optical signal;  
applying the code to the optical signal with at least one fiber Bragg grating.

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17. The method of claim 16, wherein the code is a composite code.

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18. A passive optical network, comprising at least one multiplexing station that receives a first optical signal, applies a first-level code to the first optical signal, and transmits a coded first optical signal; and that receives a second optical signal, decodes a first-level code from the second optical signal, and transmits a resulting decoded optical signal.

19. The passive optical network of claim 18, further comprising a second-level multiplexing station that receives an optical signal from the first-level multiplexing station and decodes the optical signal to decode a second-level code.

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20. The passive optical network of claim 19, wherein the second-level multiplexing station applies a second-level code to an optical signal that is transmitted to the first-level multiplexing station.

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21. A communication system, comprising:

a user station that transmits an optical signal;

a second-level mux station that receives the optical signal and applies a second-level code to the optical signal, thereby producing an encoded optical signal;

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a first-level mux station that receives the encoded optical signal from the second-level mux station and applies a first-level code to the encoded optical signal producing a composite-coded optical signal; and

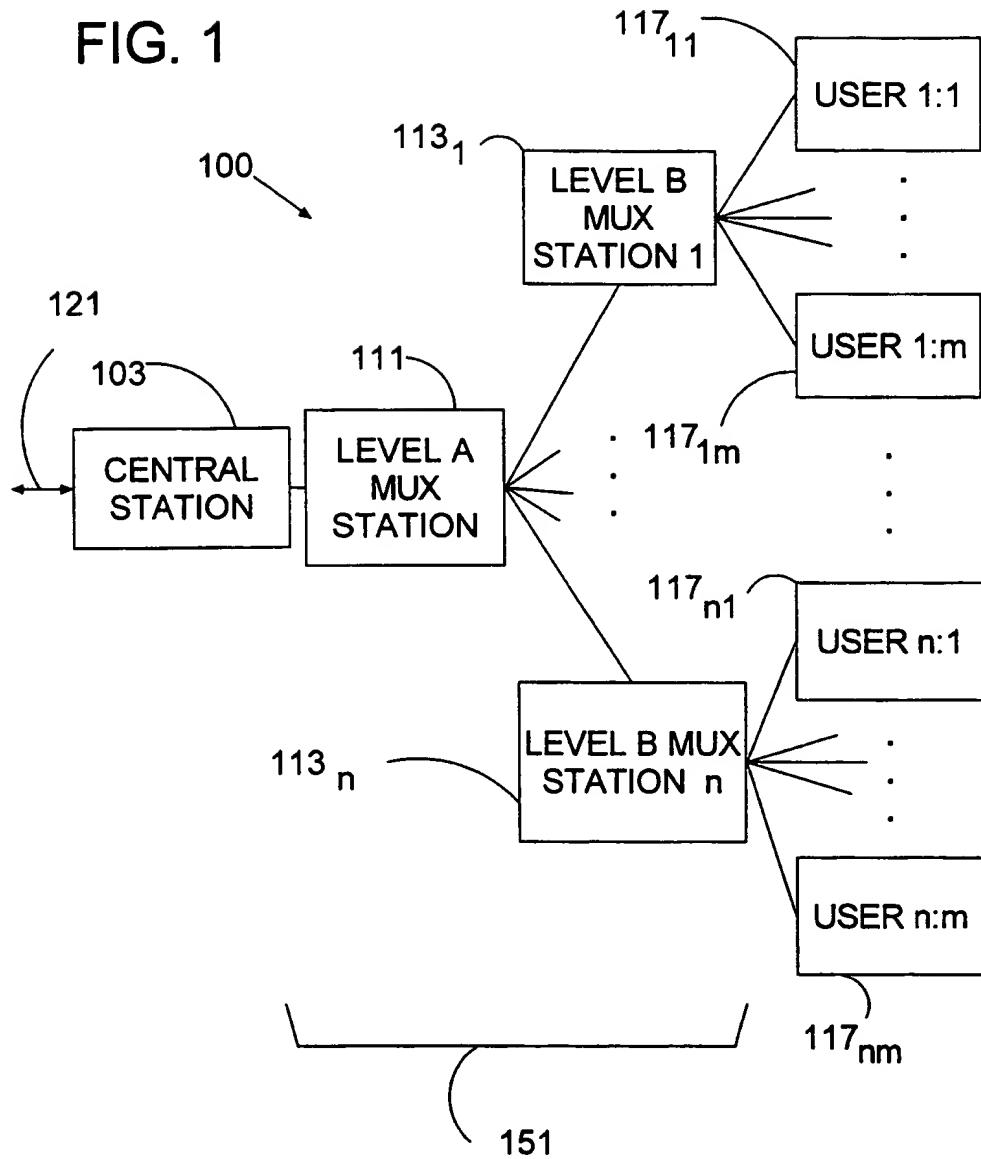
a central station that receives the composite-coded optical signal and decodes the first-level code and the second-level code to identify

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the user station that transmitted the optical signal.

1/10

FIG. 1



2/10

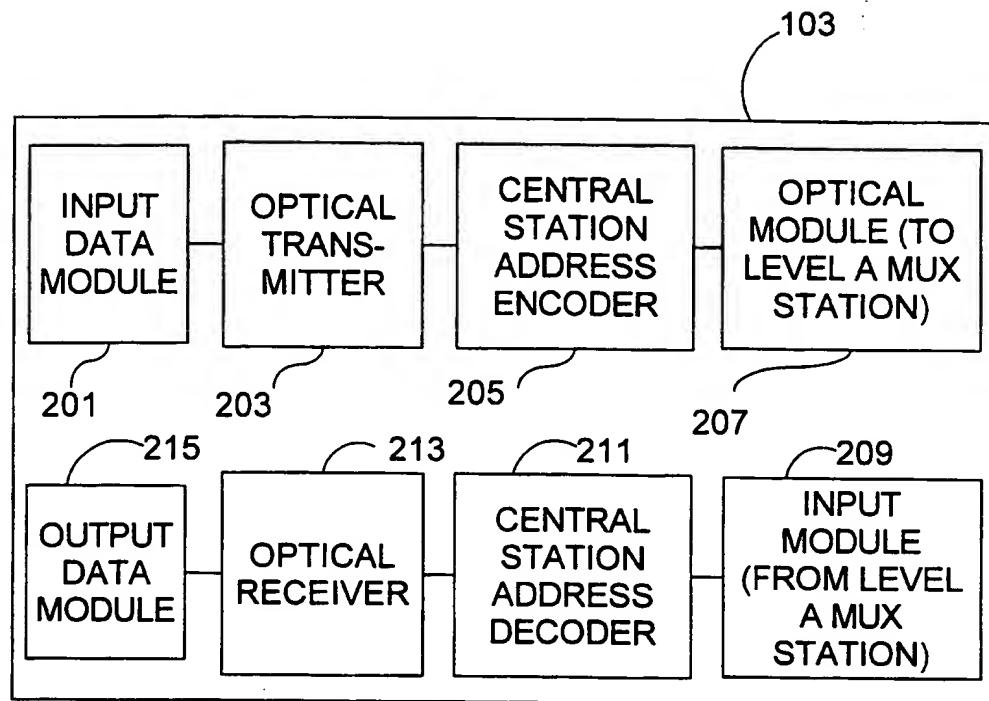


FIG. 2

3/10

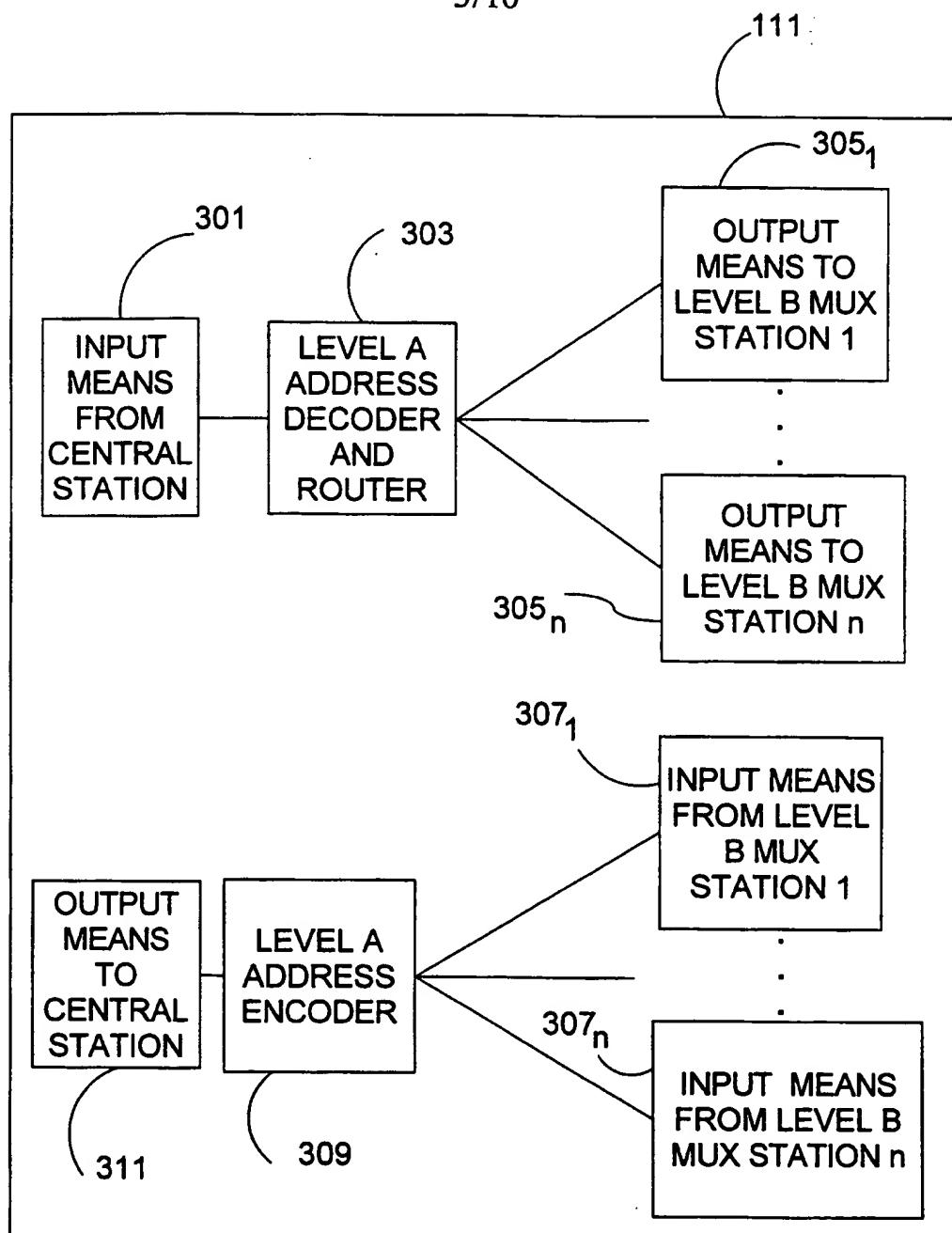
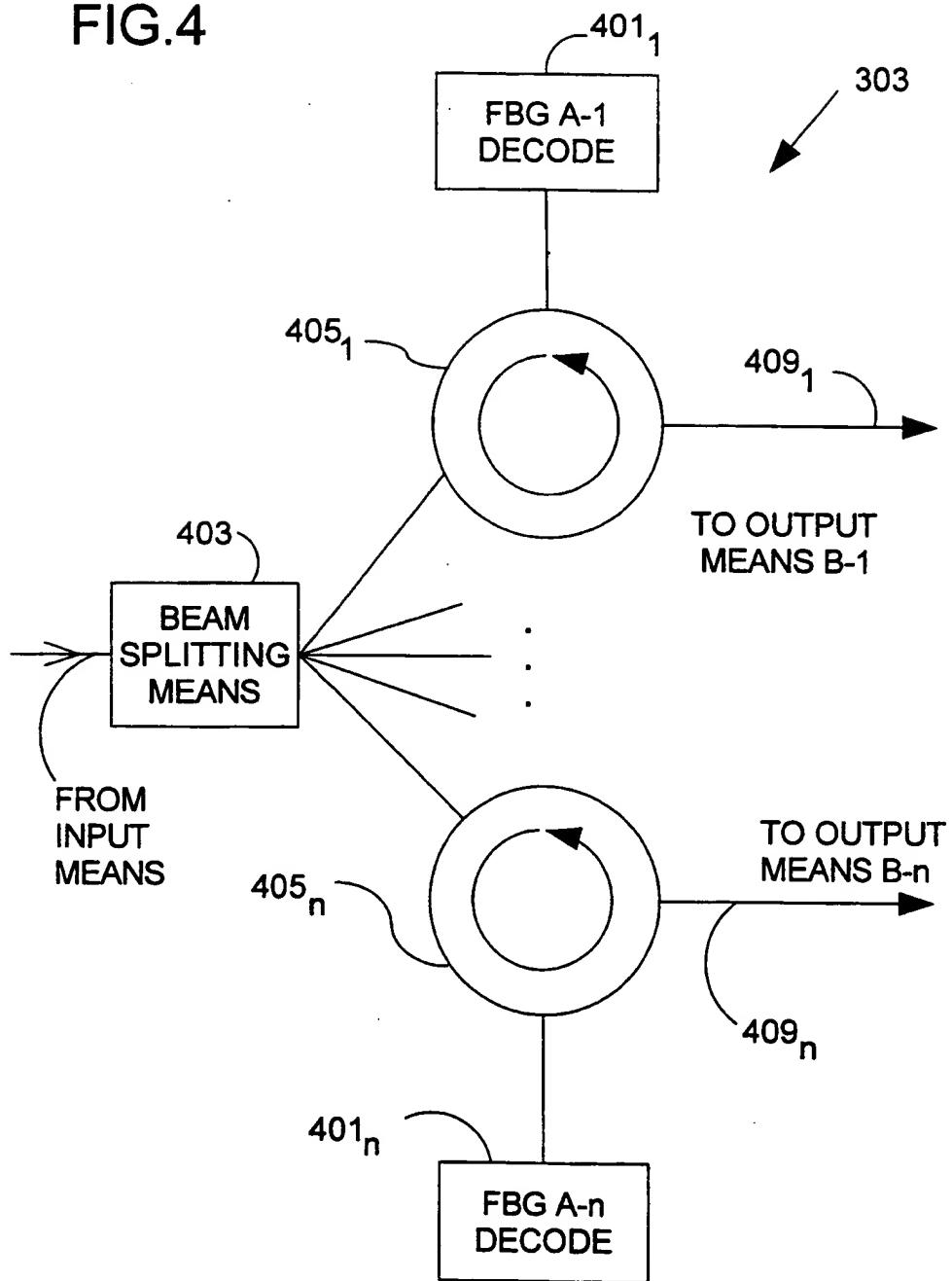


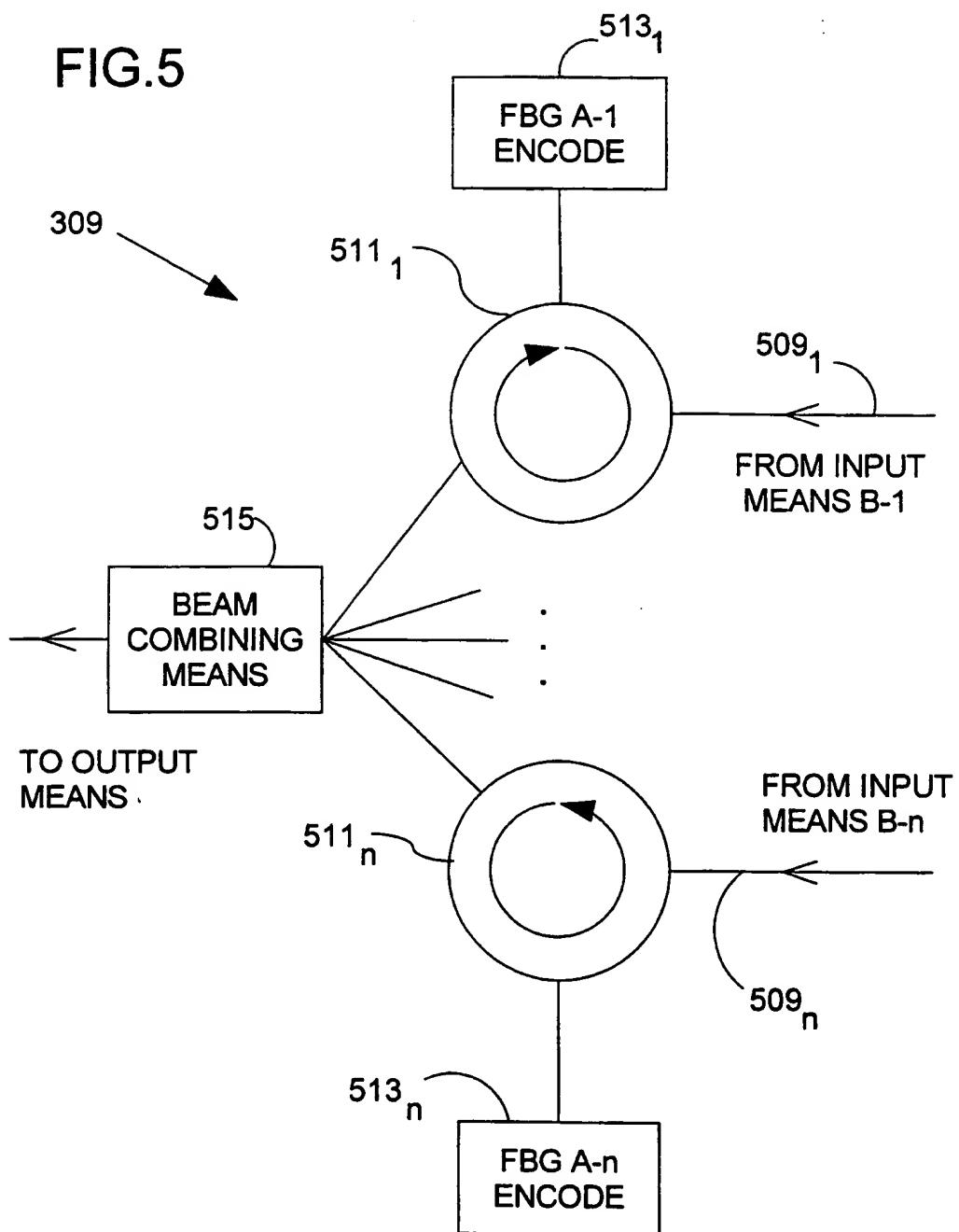
FIG. 3

4/10

FIG.4



5/10

**FIG.5**

6/10

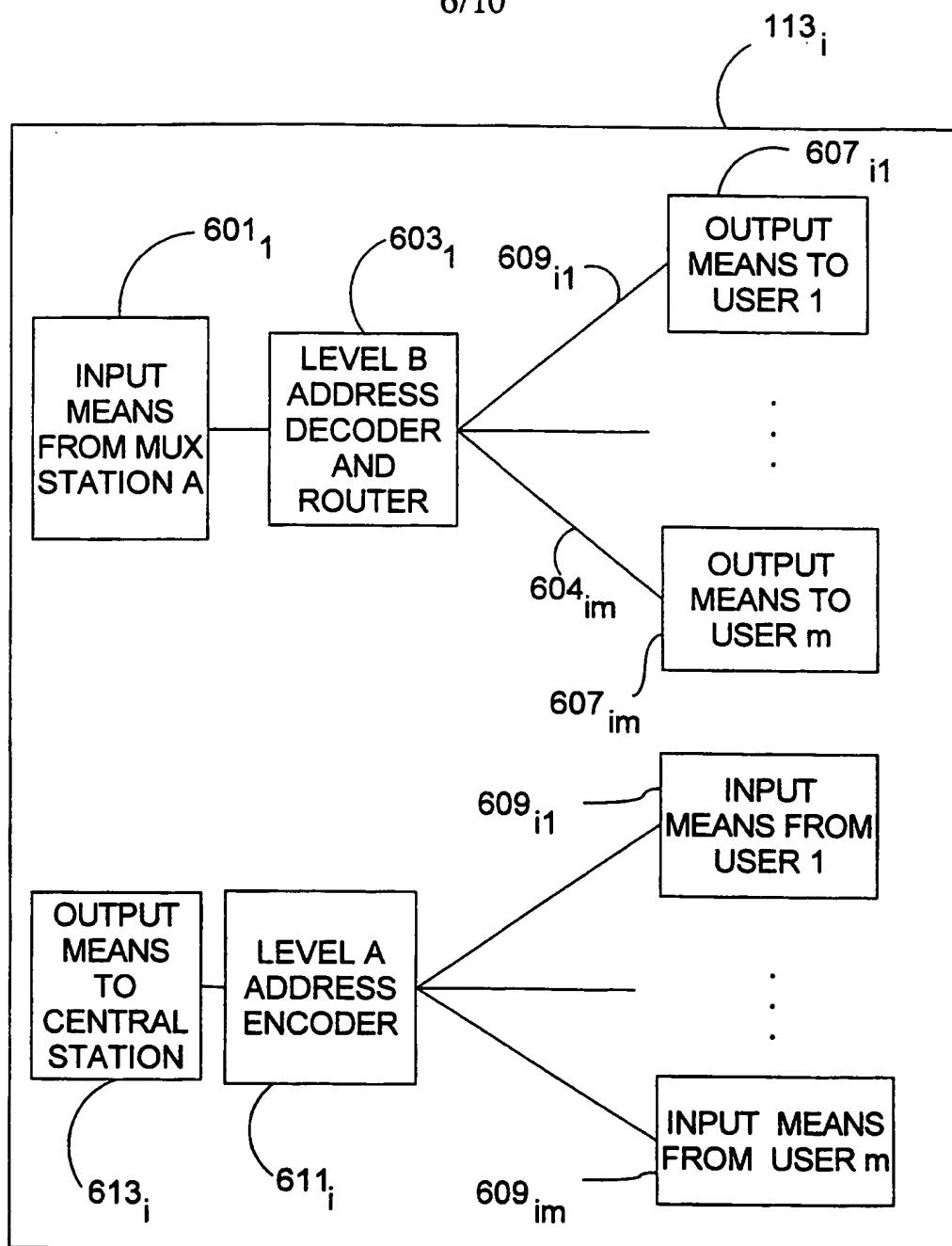
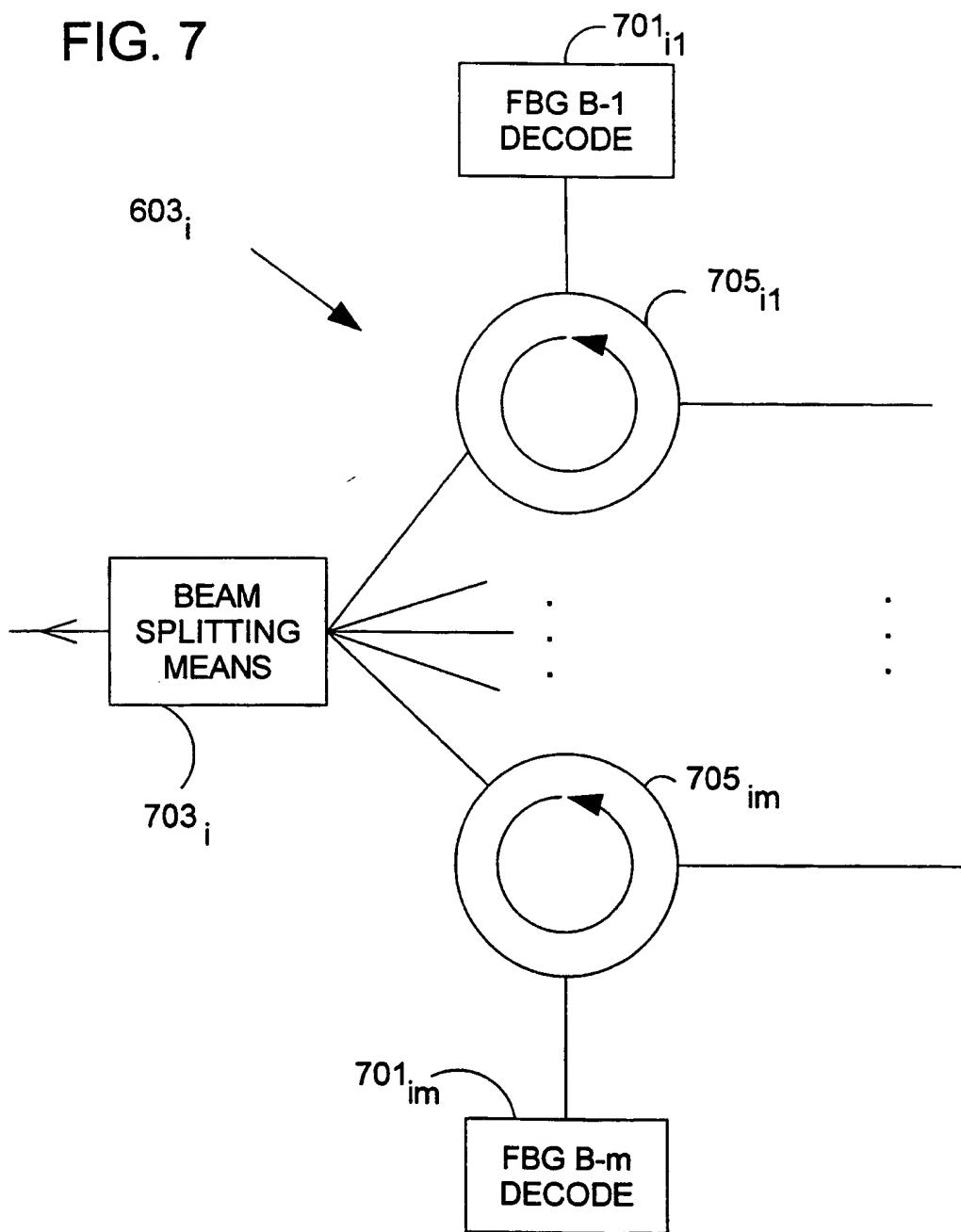
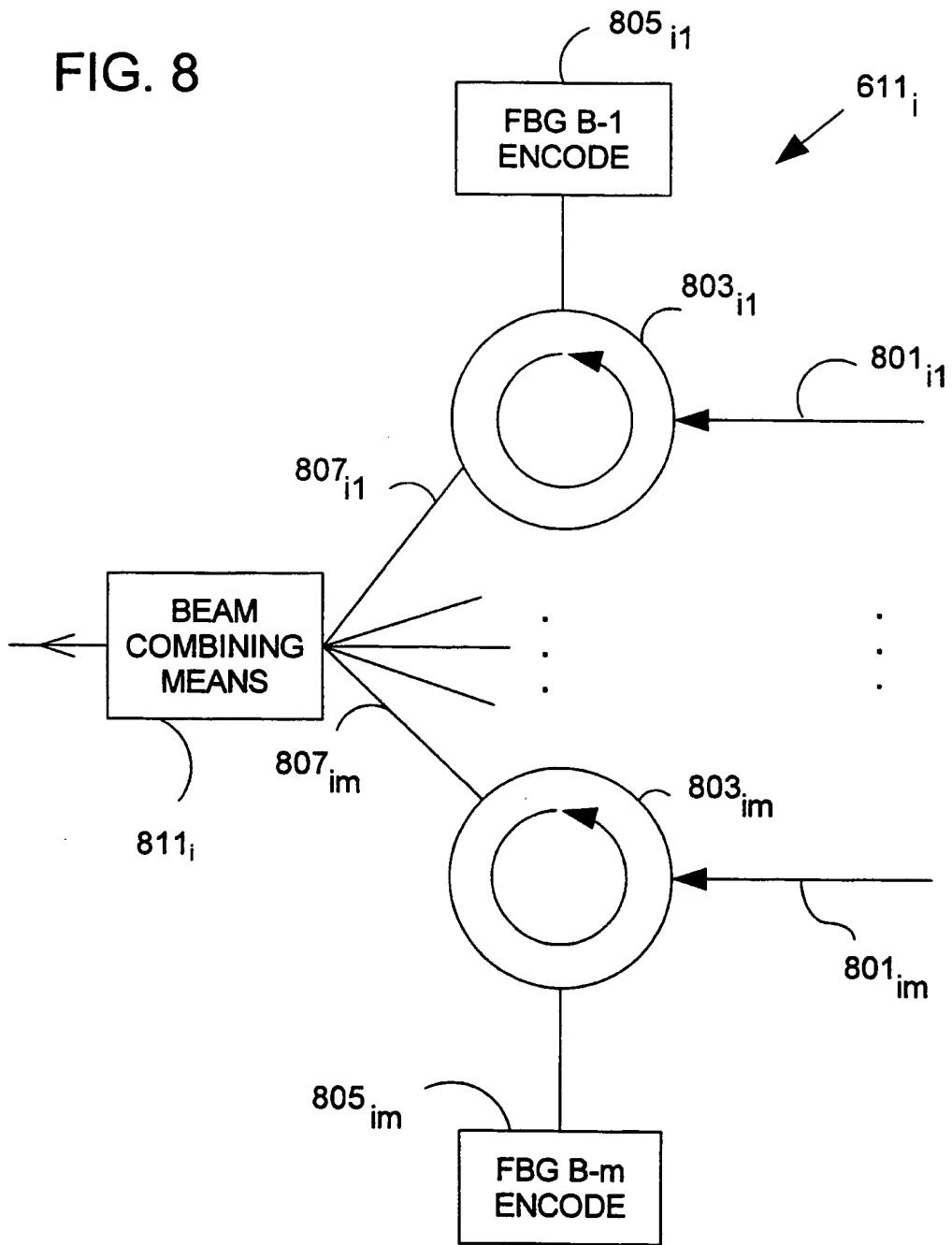


FIG. 6

**FIG. 7**

**FIG. 8**

9/10

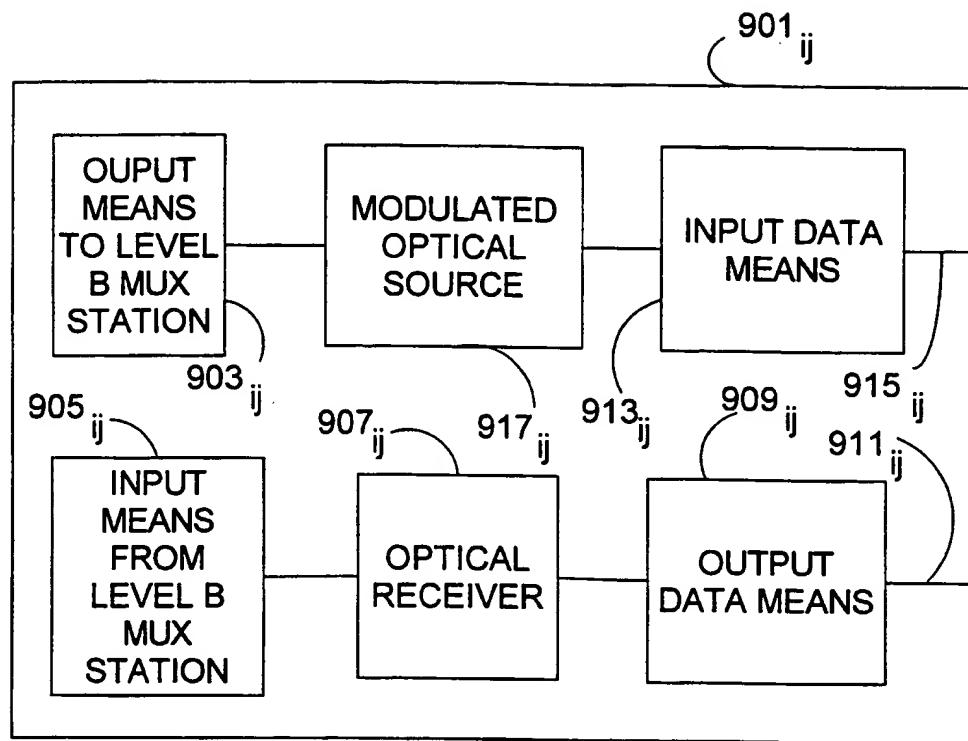
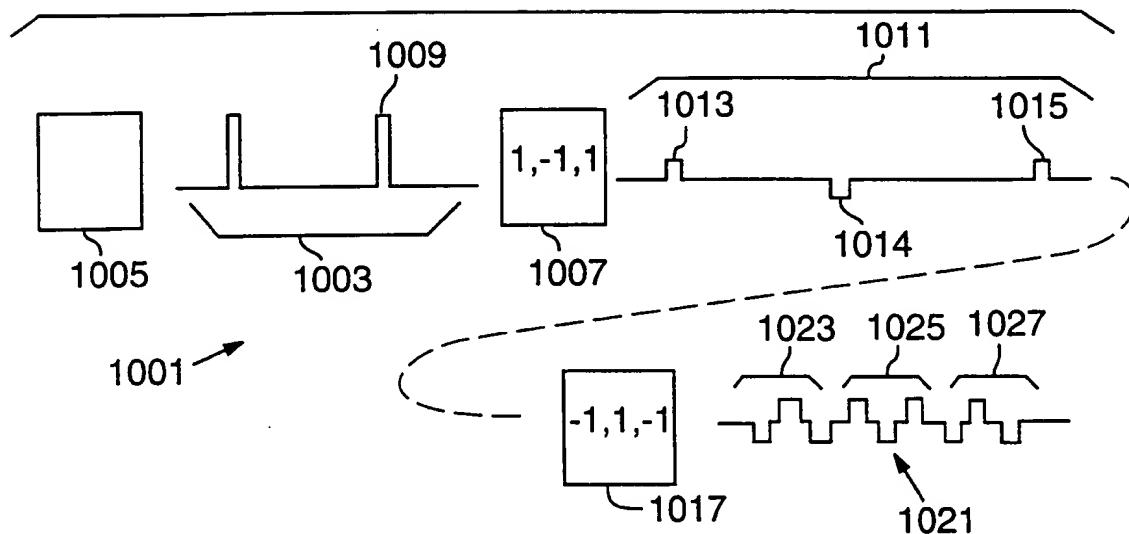


FIG. 9

10/10

FIG. 10



# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/27350

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :Please See Extra Sheet.

US CL :Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : U.S: 359/110, 115, 181, 134, 130 ; 370/93, 441, 342; 385/24, 37

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST, WEST

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,742,416 A (MIZRAHI) 21 April 1998, col. 3, lines 52-67, col. 4, lines 1-67, col. 5, lines 36-67, col. 6, lines 1-67, col. 10, lines 14-67, col. 11, lines 1-62.	1-21
Y	US 5,712,932 A (ALEXANDER et al) 27 January 1998, col. 3, lines 54-67, col. 4, lines 1-67, col. 5, lines 1-67, col. 6, lines 1-67.	13-16
Y	US 5,805,583 A (RAKIB) 08 September 1998, col. 4, lines 34-67, col. 6, lines 52-67, col. 21, lines 20-67.	1-3, 5-12
Y	US 5,760,941 A (YOUNG et al) 02 June 1998, col. 9, lines 56-67, col. 10, lines 1-67, col. 13 lines 18-67, col. 14, lines 6-67, col. 16, lines 14-67, col. 18, lines 22-67.	8-12

Further documents are listed in the continuation of Box C.  See patent family annex.

• Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance		
"E" earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&"	documents member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search  27 JANUARY 2000	Date of mailing of the international search report  10 FEB 2000
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Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer  JASON CHAN Telephone No. (703) 305-3900  <i>James R. Matthews</i>
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**INTERNATIONAL SEARCH REPORT**

International application No. PCT/US99/27350
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,784,506 A (PFEIFFER) 21 July 1998, col. 2, lines 64-67, col. 3, lines 1-67, col. 4, lines 1-54.	1-12, 17-21
Y	US 5,793,907 A (JALALI et al) 11 August 1998, col.11, lines 62-67, col. 12, lines 1-67.	8, 9
Y	US 5,790,287 A (DARCIE et al) 04 August 1998, col. 3, lines 54-67, col. 4, lines 1-67.	1-5, 18-21
Y	US 4,779,266 A (CHUNG et al) 18 October 1988, col. 3, lines 12-67.	8, 9, 11
X,P	US 5,841,776 A ( CHEN ) 24 November 1998, col. 3, lines 54-67, col. 4, lines 1-67.	1-12, 18-21

**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US99/27350

**A. CLASSIFICATION OF SUBJECT MATTER:**

IPC (6):

IPC (6): H04J 14/02, 14/08, 13/00, 14/00, 3/24; G02B 6/293, 6/28; G02B 6/26; H04B 7/216, 10/28

**A. CLASSIFICATION OF SUBJECT MATTER:**

US CL :

U.S: 359/110, 115, 181, 134 , 130 ; 370/93, 441, 342; 385/24, 37